RECENT RESULTS FROM CHORUS CHARM ANALYSIS

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The CHORUS experiment was designed to search for $\nu_\mu \rightarrow \nu_\tau$ oscillation by detecting the decay topology of the τ in charged current (CC) ν_τ events. The detector was exposed to the Wide Band Neutrino Beam of the CERN SPS during the years 1994-1997. About $10^6 \nu_\mu$ CC events were collected in the nuclear emulsion target. Up to now, about 170,000 ν_μ events have been located and analysed. The speed of the automated emulsion scanning systems increases each year. With the present performance of these systems, it has become possible to perform large volume scanning. All tracks belonging to an interaction vertex can be recognized and measured precisely. This technique is not only applied to the search for neutrino oscillation but can also be used for the recognition of events where charmed particles are produced. Results obtained from the analysis of a sub-sample of the data on the production rate in ν_μ CC interactions of neutral charmed mesons (D^0) and charmed baryons (Λ_c) are presented. In addition a new measurement of the branching ratio for the decays of charmed hadrons into muons is given. Also measurements of topological branching ratios of D^0 and Λ_c are presented. Finally, a search for associated charm production is discussed.

1 Introduction

1.1 The CHORUS experiment

The CHORUS experiment was proposed primarily to search for $\nu_\mu \rightarrow \nu_\tau$ oscillations through the appearance of ν_τ in a ν_μ beam, aiming to explore the domain of small mixing angles down to $\sin 2\theta_{\mu\tau} \sim 3 \times 10^{-4}$ for mass parameters $\Delta m^2 \sim 1$ eV^2. This represents an order of magnitude improvement over the previous generation of experiments[1].

The CHORUS detector is a hybrid set-up that combines nuclear emulsion stacks with various electronic detectors. The nuclear emulsion acts both as target for neutrino interactions and as detector, allowing three-dimensional reconstruction of short-lived particles as the τ^- lepton and charmed hadrons. The nuclear emulsion target, which is segmented into four stacks, has an

overall mass of 770 kg, each of the stacks consisting of eight modules of 36 plates of size 36×72 cm^2. Each plate has a 90 μm plastic support coated on both sides with 350 μm emulsion layers. Each stack is followed by three interface emulsion sheets having a 90 μm emulsion layer on both sides of an 800 μm thick plastic base and by a set of scintillating fiber tracker planes. The interface sheets and the fiber trackers provide accurate particle trajectory predictions into the emulsion stack in order to locate the vertex positions. The accuracy of the fiber tracker prediction is about 150 μm in position and 2 mrad in the track angle. The major drawback is the absence of the time information: any charged particle traversing the emulsion during the exposure will leave a track.

The emulsion scanning is performed by fully automatic microscopes equipped with CCD cameras and a read out system, called *Track Selector*[2]. In order to recognize track segments in an emulsion, a series of tomographic images are taken by focusing at different depths in the emulsion thickness. The digitized images are shifted according to the predicted track angle and then added. The presence of aligned grains forming a track is detected as a local peak of the gray level of the summed image. The track finding efficiency of the track selector is higher than 98% for track slopes less than 400 mrad.

The electronic detectors downstream of the emulsion target include a hadron spectrometer which measures the bending of charged particles in an air-core magnet, a calorimeter where the energy and direction of showers are measured and a muon spectrometer which measures the charge and momentum of muons.

1.2 Data Collection

The West Area Neutrino Facility (WANF) at CERN provides a beam of 27 GeV average energy consisting mainly of ν_μ with a 5% $\bar{\nu}_\mu$ contamination. For the four years in which the emulsion target was exposed, the integrated beam intensity corresponds to 5.06×10^{19} protons on target. The analysis of the data from the electronic detectors allows the identification of the set of events possibly orginating from the emulsion stacks. For the first phase of the analysis, the events were subdivided into two classes, based on electronic detectors, which are the one-muon and the zero-muon samples, distinguished by the presence or absence of one reconstructed muon of negative charge. For vertex location, track trajectories belonging to reconstructed events in the electronic detectors are used to guide the scanning. The track is first searched in the interface sheets and then followed back into the target emulsion. If it is not found in two consecutive plates, the first of these is defined as *vertex plate*. This plate may contain the primary vertex or the decay vertex, or both. Once the vertex is located, the charm decay search is performed using the *netscan* method[3]. It consists of recording all track segments within an angular acceptance in a volume surrounding the assumed vertex position.

2 Charm analysis

Charm production in neutrino charged current (CC) interactions has been studied in several experiments[4] with electronic detectors and mostly through the analysis of dimuon events. In these events, the leading muon is interpreted as originating from the neutrino vertex and the other, of opposite charge, as the product of the charmed particle semileptonic decay. Experiments of this type, however, suffer from a significant background of events ($\sim$ 30%) in which the second muon originates from an undetected decay in flight of a pion or a kaon rather than from a charm decay. Moreover, the type of the charmed particle and its decay topology can not be identified in these experiments. Nevertheless they have provided measurements of the strange quark content of the nucleon as well as an estimation of the charm quark mass. A much lower level of background can be achieved using an emulsion target which provides a sub-micron spatial resolution, and

hence, the topological identification of charmed hadron decays. The statistics accumulated in this way is however very limited. Only recently, the development within CHORUS of automatic scanning devices of much higher speed has made studies of charm production with high statistics possible.

2.1 D^0 production rate measurement

In the past, D^0 production in neutrino interactions was studied in E531 experiment[1]. Only 57 D^0 events were identified and analysed. In CHORUS, we have performed an analysis with much higher statistics. About 25,000 one-muon events were analysed representing ~15% of the CHORUS data. The main criteria for the event selection are the following: at least one of the decay daughters and muon track reconstructed with more than one-segment, matched tracks in the electronic detector; and the daughter track must have a significant impact parameter with respect to the vertex point. These criteria select 851 events from 25,000 CC ν_μ events. The selected events are visually inspected in order to distinguish decays from hadronic interactions, gamma conversion and false vertices which are reconstructed using background tracks. After performing visual inspection, we confirmed that out of 851 selected events, 226 show 2-prong decay topology and 57 show 4-prong decay topology.

The efficiency of the charm selection was evaluated with a GEANT3 based simulation of the experiment. Large samples of deep-inelastic neutrino interactions were generated according to the beam spectrum using the JETTA generator derived from LEPTO and JETSET. The simulated response of the CHORUS electronic detectors is processed through the same reconstruction program used for data. To evaluate the *netscan* efficiency, realistic conditions of track densities need to be reproduced. This is achieved by merging the emulsion data of the simulated events with real netscan data which do not have a reconstructed vertex but contain tracks which stop or pass through fiducial volume representing the real background[5]. The combined data are passed through the same netscan reconstruction and selection programs as used for data. The selection efficiencies are estimated as (58.6±5.1)% and (70.1±5.2)% for 2-prong and 4-prong decays respectively. Based upon 282 D^0 decays with an estimated background of 9.2±2.6 K^0 and Λ^0, we obtain[6]: $\frac{\sigma(D^0\to V2+V4)}{\sigma(\mathrm{CC})}=(1.99\pm0.13(stat.)\pm0.14\ (syst.))\times10^{-2}$ at 27 GeV. The topological ratio V4/V2 is found to be

$$(23.1 \pm 4.0)\% \tag{1}$$

Combining (1) with $Br(D^0 \to V4) = (13.3 \pm 07) \times 10^{-2}$ using the PDG tables[7], we can obtain branching ratio of D^0 decaying into neutral particles:

$$Br(D^0 \to neutral) = 1 - Br(D^0 \to V4) \times (1 + (\frac{Br(D^0 \to V4)}{Br(D^0 \to V2)})^{-1}) \tag{2}$$

$$= (29.1 \pm 10.4) \times 10^{-2}$$

The precision of this measurement will be improved with the final statistics.

2.2 Semi-leptonic branching rate measurement

To measure the semi-leptonic branching ratio, the event the event selection criteria are the following: at least two tracks of more than one-segment coming from different vertices match tracks at the electronic detectors. About 50,000 ν_μ CC events are analysed with this selection and in total, 1055 events are selected. To estimate the selection purity, 25% of selected events are visually inspected. The selection purity is obtained as 91%. Based on this selection purity, the number of charmed hadrons is 956±35.

The efficiency of charm selection was evaluated as explained in the previous section. The correction factor (R) for the efficiency in the determination of the semileptonic branching fraction is defined as $\frac{\Sigma_{D_i}\epsilon_{D_i} f_{D_i}}{\Sigma_{D_i}\epsilon_{D_i^{\mu}} f_{D_i}}$ where ϵ_{D_i} is the selection efficiency for charm species D_i , $\epsilon_{D_i^{\mu}}$ the selection efficiency for semileptonic decays of D_i, f_{D_i} the fragmentation fraction. Based on the estimated efficiencies R is 1.01$\pm$ 0.05.

The average semi-leptonic branching fraction can be written in terms of measurable quantities as $B_{\mu} = \frac{N_{2\mu}^{sel.}}{N^{sel.}} \times R$ where $N^{sel.}$ is the number of selected events, corrected for the selection purity and $N_{2\mu}^{sel.}$ is the number of selected events with a secondary muon in the final state corrected for selection purity as well as the muon identification efficiency and purity.

Combining these numbers, we measured $B_{\mu} = 0.0093 \pm (stat.) \pm 0.009(syst.)$.[8]

2.3 Λ_c production rate measurement

Although evidence for charmed baryon production by neutrinos has been reported in the literature with few events observed in a number of different bubble chamber experiments, cross-section values are known with a large error.

Our analysis is based on a statistical approach using the flight length distributions of charmed hadrons. Since the lifetime of the Λ_c is smaller than that of other charged charm hadrons, the sample of charged charm decaying at distances less than 400 μm from the ν vertex, called short decays, should be dominated by Λ_c. Conversely, long decays are enriched by D^+ and D_s^+ decays. Therefore, the analysis is performed applying two different selections. Event selection for short flight decays is based on the following: muon track and daughter track must be reconstructed having more than one segment and the daughter track must have a big impact parameter with respect to the vertex point (5μm $<$ IP $<$ 30 μm). We have analysed about 50,000 CC ν events with short decay selection criteria. In total, 1614 events were selected for visual inspection. 62 events are confirmed as 1-prong decay and 66 events show 3-prong decay topology.

On the other hand, for long flight decays we require that the parent track and muon track must be reconstructed by the reconstruction software and the parent track must have a small impact parameter with respect to the neutrino vertex and at least one of the daughter tracks must be reconstructed with more than one segment and minimum distance between parent track and daughter track must be less than 5 μm. About 56,000 CC ν events were analysed and 586 events were visually inspected. The confirmed charm events after flight length cut are the following: 133 1-prong and 195 3-prong decays.

Combining short and long decay search and taking into account efficiency and background, the number of Λ_c is 861$\pm$198(stat.)$\pm$98$(syst.)^{+140}_{-54}(QE)$. Based on these events the branching ratio into 3-prongs was determined: BR($\Lambda_c \rightarrow 3$ $prong$)=0.24$\pm$0.07(stat)$\pm$0.04(syst.) and the total charged-current cross section[9]: $\frac{\sigma(\Lambda_c)}{\sigma(\mathrm{CC})}$=(1.54$\pm$0.35($stat.$)$\pm$0.18 ($syst.$))$\times 10^{-2}$.

2.4 Associated charm production

Associated charm ($c\bar{c}$) production in neutrino interactions is a very rare process and therefore very difficult to observe. In the past, $c\bar{c}$ production in charged-current ν_{μ} interactions has been studied through trimuons and like-sign dimuons , however, the reported production rate is higher than theoretical expectation. On the hand, only one event consistent with neutral-current (NC) production of $c\bar{c}$ has been observed by the E531 collaboration[1]. Based on one event, the production rate with respect to NC production is estimated as $\frac{\sigma(c\bar{c})}{\sigma(\mathrm{NC})}$=(0.13$\pm$0.31) $\times 10^{-2}$. The sub-micron resolution of nuclear emulsion allows the study of this kind of rare processes. We have performed a search in CC ν_{μ} interactions and one event is observed with the characteristics of $c\bar{c}$ production[10]. A new search has been started, both in the NC and CC event sample. Fig.

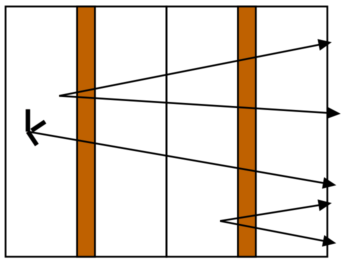

Figure 1: Sketch of the event topology in emulsion.

1. shows the schematic view of one of the candidate events. This event is found in the zero-muon sample and shows two V2 decay topologies. One minimum-ionizing particle and three heavy ionizing particles are emitted from primary vertex. A neutral particle(C^0) decays in the same emulsion plate, 62 μm downstream of the primary vertex. In the next plate, another neutral decay is found with the flight length of 977 μm. The lifetimes of the decaying particles are estimated using the relation: $\tau{=}\frac{l<\theta>}{c}$ 11 where $<\theta>$ is average emission angle of daughter particles relative to the parent direction , l is the flight lenght of the decaying particle and c is the speed of light. The estimated lifetimes, shown in table 1, are consistent with the decay of the neutral charmed particles. The search for new candidates and more detailed analysis of already observed events are in progress.

Table 1: List of particles at primary and secondary vertices.

	$\theta_y(rad)$	$\theta_z(rad)$	$l(\mu\text{m})$	τ(s)
particle1	-0.060	-0.002		
$1-C^0$	0.008	0.031	63	2.6×10^{-14}
daughter (at 1-C^0)	-0.019	0.040		
daughter (at 1-C^0)	-0.052	0.028		
2-C^0	-0.078	0.095	977	5.5×10^{-13}
daughter (at 2-C^0)	-0.166	0.049		
daughter (at 2-C^0)	0.035	0.103		

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